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SPECIAL REPORT

A COMPARISON OF THE DEPOSITS OBTAINED FROM AERIAL SPRAYS RELEASED AT ALTITUDES OF FIFTY AND TWO HUNDRED FEET

1951 Season

by

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A COMPARISON OF THE DEPOSITS OBTAINED FROM AERIAL SPRAYS RELEASED AT ALTITUDES OF FIFTY AND TWO HUNDRED FEET

INTRODUCTION

In the past, 50 feet above the canopy has been accepted as the standard altitude for spraying with light planes over forests. Several agencies active in aerial spraying have wanted to increase the recommended flight altitude in order to decrease the danger of this type of flying. The Forest Insect Laboratory at Beltsville was requested to determine in single swath tests over open ground what possible effects an increased flight altitude would have on amount and distribution of spray deposit. Because of the limited area available here for sampling deposit the altitude chosen for comparison with 50 feet was 200 feet. At higher altitudes the spray was carried off the sampling area. A fine atomization was tried in preliminary tests but, here too, a considerable amount of the spray was deposited outside the sampling area. A medium atomization, 150 microns mmd (mass median diameter), was used on all flights. It was considered necessary to investigate the effect of altitude under both crosswind and upwind conditions. The experiment was set up so that comparisons could be made among the following four groups:

I. upwind flights at 50 foot altitude
II. crosswind flights at 50 foot altitude
III. upwind flights at 200 foot altitude
IV. crosswind flights at 200 foot altitude

PROCEDURE

I. AIRCRAFT, SPRAY APPARATUS AND OPERATIONAL PROCEDURE

Two Stearman biplanes were used in these tests. The dispersal apparatus was a boom located 8 to 9 inches below the lower wing and extending to within about 8 inches of each wing tip. Either 11 or 12 nozzles, with the orifices facing forward, were on each side of the center line of the boom. About 60 per cent of the nozzles were placed in the outboard half of the boom. The nozzle used was the Spraying Systems Co. B5 or A5 which has an orifice diameter of 1/8 inch and delivers a hollow cone spray pattern. This apparatus delivered a spray of medium atomization (150 microns mmd) at the rate of 20.8 – 22.5 gpm (gallons per minute). Pressure varied from 20 to 27 psi (pounds per square inch). Flights in 50 foot tests were flown at 40 to 50 feet; in 200 foot tests from 180 to 200 feet. Indicated air speeds ranged from 78 to 85 mph (miles per hour).

III. SPRAY FORMULATION

The standard solution of the Beltsville laboratory is:

DDT, technical	1.0 pound
Sovacide 544-B	1.0 quart
Tracer dye	0.32 ounce
Fuel oil No. 2 to make	1.0 gallon

This formulation was used in the 1950 flights included in this study with either Dupont Oil Red or Sudan Blue as the tracer dye. In 1951 it was used for 50 foot altitude flights through October 17 with Alizarine Irisol dye as the tracer. After that date the following reduced DDT formulation was used for 50 foot flights:

DDT, technical	0.25 pound
Sovacide 544-B	2.06 quarts
Alizarine Irisol	0.32 ounce
Fuel oil No. 2 to make	1.0 gallon

The spray used for all high altitude flights was straight Sovacide 544-B with 0.8 ounce of Calco Oil Orange dye per gallon added as a tracer. All these sprays had approximately the same viscosity and density.

III. SAMPLING

The experiment consisted of a sample of 30 flights arranged in four groups as shown in Table 1. In each flight a sample line was set at right angles to the line of flight with stations at spaced intervals along the line. At each station 2 aluminum plates were placed horizontally for sampling spray deposit. In upwind flights the area of the 2 plates was 1/2 square foot; in crosswind flights it was 2 square feet. In Group I the station interval was 5 feet, in Group III it was 10 feet; in Group II station intervals varied from 20 feet, near the point where the plane passed over the line, to 300 feet, in the downwind end of the swath; and in Group IV the stations were either 100 or 300 feet apart. The plates were exposed to the spray for a period long enough to allow the spray to settle or to be moved beyond the sampling line by the wind. (See Sampling Time in Table 1).

IV. DEPOSIT ANALYSIS

The deposit plates were collected and spectrophotometer readings of the dye tracer were made in the laboratory, giving a gpa (gallon per acre) reading for each station. In order to determine if and how much dye fading occurred, the total gpa for the sample line as determined from chlorine analysis for DDT content was compared with the total gpa as determined by the spectrophotometer readings*. The resulting ratio was very near one in

* This comparison was possible only with the 50 foot flights, as no DDT was used in the 200 foot flights.

some of the flights but in others it was quite irregular. Experimental error was held as much responsible for the irregularities as fading, and therefore the ratio could not be used as a test of the reliability of the data. However, to minimize the possibility of fading, most of the tests were made at sundown and, in 1951, two dyes were used that were known to be fairly light fast.

V METEOROLOGICAL RECORDS

The experimental conditions that varied from flight to flight are presented in tabular form (Table 1). The meteorological data were recorded at a weather station near the test area. A 50 foot hinged pole to support instruments was raised at the station before each flight. Continuous readings were taken on an operation recorder of the wind speed and, to within 11.25 degrees, of the wind direction. The instruments for direction and speed did not record accurately below 1 mph. Wind direction, as shown in Table 1, is given relative to the flight line and is a mean taken over the first 5 minutes following flight time. For example, looking at the record in Table 1 for Flight 1 of Group III, 3R indicates that the mean wind direction at ground level was 3 degrees to the pilot's right. It should be remembered that the direction given is a mean and that actually the wind varies around it. In this particular case, the wind varied from 5 degrees to the left to 18 degrees to the right of the flight line. The component of this wind vector at right angles to the line of flight was called the drift component. Temperature was measured by remote indicating telethermobulbs. The stability of the air, or temperature gradient, was expressed by subtracting the low altitude temperature from the high. A positive number denotes inversion, a negative denotes lapse, and 0 indicates that the temperature was the same at both levels. Relative humidity was determined on the ground by a sling psychrometer.

VI. ASSEMBLY OF DATA

Per cent recovery (the amount of spray deposited divided by the amount of spray released) was determined by formula, while all subsequent measurements - maximum deposits, swath width and uniformity of deposit - were made from deposit curves. A deposit curve or profile of the deposit distribution was plotted for each flight with the gpa reading for each station on the vertical scale and the distance of the station from the flight line on the horizontal scale.

Table 1. Experimental conditions for the test flights. (See text for detailed explanation)

Flight Number	Date	Flight Time	Sample Time	Meteorological: Wind at 5 feet: Dir.**	Speed	Drift Comp.	Temp.	Wind at 50 feet: Dir.**	Speed	Drift Comp.	Temp.	Temp. Grad.	Hum.
		hours	min.	deg.	mph	mph	°F	deg.	mph	mph	°F	°F	%
GROUP I UPWIND FLIGHTS AT 50'													
1	7-27-50	2030	10	—	—	—	72	—	—	—	72	0	92
2	9-14-50	1935	10	43R*	0	0	64	13R	0	0	65	+1	96
3	9-25-50	1802	10	5R	1.0	<1R***	46	28L	3.6	1.7L	49	+3	92
4	10-26-50	1728	10	15L	1.2	<1L	47	8R	2.0	<1R	49	+2	—
5	11-1-50	1716	10	6R	1.8	<1R	72	10L	4.2	<1L	76	+4	92
6	8-13-51	1003	10	45R	0	0	77	13L	0	0	78	+1	79
7	8-16-51	1952	13	—	3.2	—	82	0	6.4	0	83	+1	82
8	9-11-51	1955	14	10L	1.2	<1L	71	45L	3.2	2.3L	72	+1	79
9	9-12-51	1910	10	17L	1.8	<1L	76	23L	4.8	1.9L	76	0	78
10	9-17-51	1909	11	2R	1.0	<1R	62	20R*	1.6	<1R	64	+2	78
11	10-26-51	1714	20	7L	1.6	<1L	58	53L	3.5	2.8L	62	+4	57
GROUP II CROSSWIND FLIGHTS AT 50'													
1	10-9-51	1730	20	70L	<1	<1L	54	56L*	1.0	<1L	55	+1	76
2	10-16-51	1728	14	88L	1.8	1.8L	64	24R*	3.6	1.5R	67	+3	70
3	10-17-51	1723	17	82L	4.2	4.2L	67	71L*	6.8	6.4L	68	+1	75
4	10-30-51	1024	9	—	8.0	—	58	80R*	10.0	9.8R	58	0	62
5	10-31-51	0951	10	—	1.0	—	65	85R*	2.0	2.0R	62	-3	76
6	11-5-51	1706	7	70R*	1.8	1.7R	36	75R	4.4	4.2R	38	+2	56

* Tailwind

** Relative to flight direction as determined by pilot's right or left

*** < means less than

Table 1 continued

Flight Number	Date	Flight Time	Sample Time	Meteorological: Wind at 5 feet Dir.**	Speed	Drift Comp.	Temp.	Wind at 50 feet Dir.**	Speed	Drift Comp.	Temp.	Temp. Grad.	Hum.
		hours	min.	deg.	mph	mph	°F	deg.	mph	mph	°F	°F	%
				GROUP III UPWIND FLIGHTS AT 200'									
1	9-21-51	1904	24	3R	3.2	< 1R	70	18L	7.0	2.2L	72	+2	74
2	9-24-51	1646	29	44R	2.4	1.7R	66	15L	4.6	1.2L	66	0	62
3	9-25-51	1815	31	13R	< 1	< 1R	78	10L	1.6	< 1L	78	0	59
4	9-26-51	1841	29	8L	< 1	< 1L	61	8L	2.0	< 1L	64	+3	62
5	10-23-51	1715	25	15R	3.2	< 1R	65	25L	6.8	2.9L	66	+1	62
				GROUP IV CROSSWIND FLIGHTS AT 200'									
1	8- 8-51	1955	20	75L	3.0	2.9L	74	—	< 1	—	78	+4	78
2	8-10-51	2006	20	68L	1.0	< 1L	87	25R*	—	—	87	0	79
3	8-23-51	1939	20	70R	1.0	< 1R	—	48R	1.8	1.3R	—	—	73
4	8-24-51	0946	20	62R*	6.2	5.5R	77	26R	7.6	3.3R	73	-4	52
5	8-29-51	1858	32	75L	< 1	< 1L	81	75L	2.2	2.1L	82	+1	48
6	9- 5-51	1858	28	87L*	2.2	2.2L	72	65L*	4.4	4.0L	72	0	66
7	9- 7-51	0926	23	80R	6.0	5.9R	76	59R	9.2	7.9R	74	-2	65
8	9-10-51	1928	17	74L	4.0	3.8L	68	87L	8.4	8.4L	70	+2	74

* Tailwind
** Relative to flight direction as determined by pilot's right or left
*** < means less then

RESULTS

AMOUNT OF SPRAY RECOVERED

Per cent recovery is computed by the formula:

$$\frac{2C2 \Sigma X \; I \; S}{R}$$

Where ΣX = total deposit at all stations in mpa

I = distance between stations in feet

S = speed of plane in mph

R = flow rate in gpm

These quantities can be measured with only limited accuracy and as a result the expected experimental error for recovery is ± 10 per cent or more. The value for each flight and the mean value for each group are given in Table 2. It is evident that recovery was affected more by uncontrollable factors that varied from flight to flight within a group than by the factors that varied from group to group. An analysis of variance of this data was made (Table 3) and the F test of significance showed that there was no significant difference between the means given in Table 2. The data indicate that under conditions similar to those of this experiment the flight altitude can be increased without decreasing per cent recovery.

Table 2. Per cent recovery

Flight Number	Group 1. Up 50'	2. X 50'	3. Up 200'	4. X 200'
1	67	70	70	81
2	54	78	69	74
3	71	44	84	79
4	85	27	76	106
5	66	74	66	72
6	90	56		58
7	57			58
8	64			86
9	61			
10	65			
11	59			
Mean	67	58	73	77

Table 3. Analysis of variance of per cent recovery

Source	d.f.*	Sum of Squares	Mean Square	F	Significance
Total	29	6504.40			
Treatment	3	1314.44	438.15	2.195	Not sig.
Error	26	5189.96	199.61		

* degrees of freedom

II. DISTRIBUTION OF SPRAY DEPOSIT

A. Maximum deposit

Maximum deposit for each flight and each group are given in Table 4. An analysis of variance and F test applied to the data showed that the variance due to differences between the 4 groups was significant. The following four comparisons were then made:

Comparison	LSD*	Difference between 2 means
Upwind at 50 and at 200 feet	0.14	0.57
Crosswind at 50 and at 200 feet	0.15	0.26
50 feet, X wind and upwind	0.12	0.92
200 feet, X wind and upwind	0.16	0.61

*Least significant difference at the .05 probability level.

These analyses show that:

1. Under either upwind or crosswind conditions the flights at the higher altitude had a lower maximum deposit.

2. At either 50 or 200 feet flight altitude the maximum deposit was significantly less for a crosswind flight than for an upwind.

Since there was no difference in recovery between the two altitudes it is reasonable to assume that if at the higher altitude less spray fell near the flight line in a heavy deposit, more was deposited in the tails of the swath and the total swath was increased. This is investigated in the next section.

B. Swath width

In crosswind flights total swath width (swath width over which a measurable deposit was recovered) and swath widths at minimum deposit levels of from .01 to 0.10 gpa were measured for each flight. Group averages are shown in Table 5. Within these deposit levels the mean swath width for the 200 foot tests was greater than for the 50 foot tests. However, in general, the differences were not statistically significant because of the extreme variation from flight to flight within each group.

Table 4. Maximum deposit in gpa

Flight number	Group 1. Upwind 50'	2. X wind 50'	3. Upwind 200'	4. X wind 200'
1	.96	.42	.64	.25
2	1.59	.47	.62	.35
3	.86	.18	.99	.19
4	3.60	.15	.95	.25
5	1.10	.94	.82	.16
6	1.10	.57		.11
7	.74			.06
8	1.50			.16
9	.89			
10	1.14			
11	1.64			
Mean	1.37	.46	.80	.19

In upwind flights total swath width and swath width at deposit levels of 0.10 to 0.50 gpa were measured. The 200 foot flights had wider swaths at all levels, and the difference was significant at deposit levels of 0.20, 0.30 and 0.40 gpa.

Flying at the higher altitude in either crosswind or upwind reduced the high concentration of spray under the plane and caused wider swaths at lower deposit levels. The probable reasons for these differences are discussed under section E.

Table 5. Mean swath widths at various deposit levels

Minimum deposit gpa	Swath width in feet 1. Upwind 50'	2. X wind 50'	3. Upwind 200'	4. X wind 200'
Total Swath	391	2318	629	4725
.01	–	1592	–	1603
.02	–	781	–	1095
.03	–	568	–	876
.04	–	443	–	630
.05	–	350	–	508
.10	178	172	198	228
.20	135	–	170	–
.30	113	–	151	–
.40	87	–	117	–
.50	63	–	86	–

C. Mean deposit curves

In addition to computing averages of swath width and maximum deposit, mean deposit curves were drawn. The gpa reading at a given distance from the flight line was measured on the deposit curve for each flight and these readings averaged. This was done for various distances to right or left of the flight line and the mean deposit curve was obtained by plotting a mean deposit against its distance from the flight line. A comparison of the resulting curves for the four groups showed:

1. In crosswind flights the typical deposit curve is a single light peak skewed to the downwind side of the flight line; in upwind flights the typical curve is a bimodal one nearly symmetrical with the flight line. Both upwind curves were skewed slightly to the left of the flight line. This is explained by the fact that in both groups the drift component (measured at 50 feet) was slightly to the left. For the 200 foot flights it was 1.4 mph and in the 50 foot group it was less than 1 mph.

2. In either crosswind or upwind flight the spray released at 200 feet was deposited over a wider area with less over concentration under the plane.

This information merely corroborates that obtained by measuring maximum deposit and swath width.

D. Uniformity of deposit

Deposit resulting from a series of parallel swaths can be predicted from the data of this experiment by making several assumptions:

1. The deposit curve is the same from swath to swath in spite of varying conditions such as terrain, wind, etc.

2. The flight lines are uniformly 132 feet apart.

The multiple swath distribution is a resultant of a succession of overlapping single swath deposit curves. The deposit at any point is contributed to by several swaths. The multiple swath deposit curve can be calculated from the single swath deposit curve with the above assumptions. These multiple swath deposit curves were then averaged to give a mean multiple swath deposit curve for each group. By inspection of these mean curves, shown in Figure 1, the four groups may be ranked in order of decreasing uniformity of deposit:

crosswind - 200 feet
crosswind - 50 feet
upwind - 200 feet
upwind - 50 feet

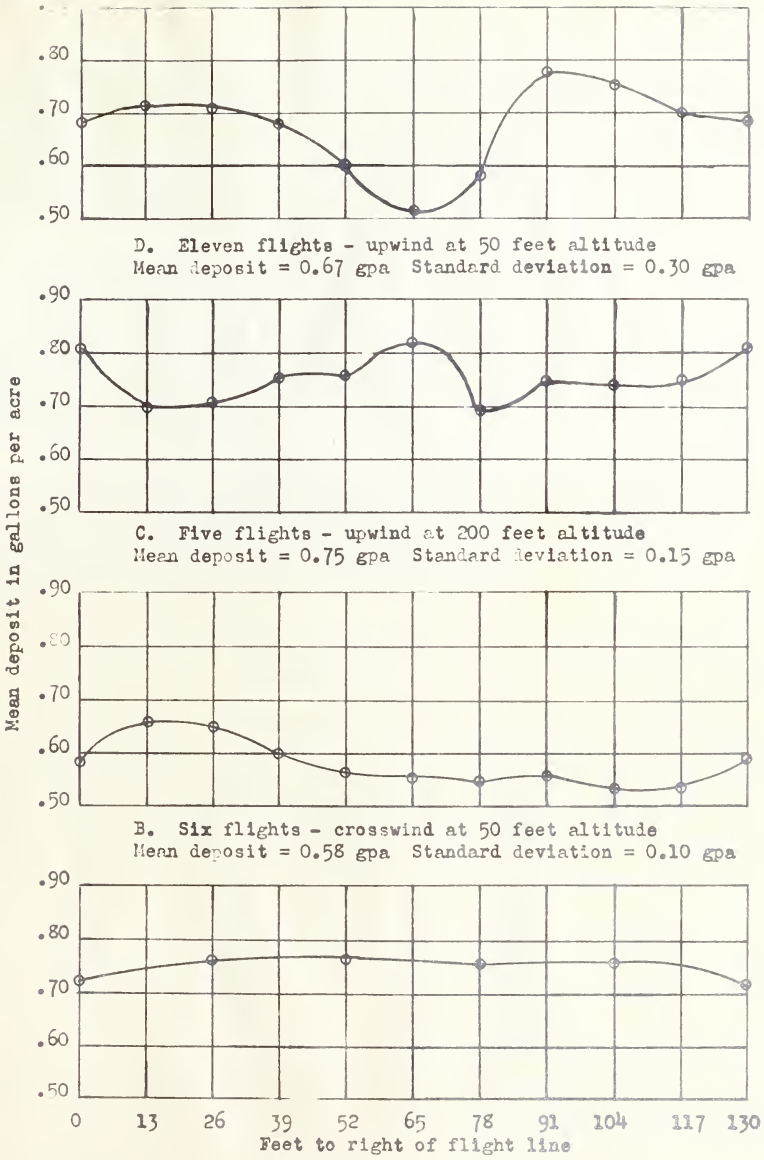

Figure 1. Mean multiple swath deposit curves

Uniformity of deposit, or the smoothness of the curve, was expressed quantitatively by finding for each flight the standard deviation of the multiple swath deposits from their mean. An analysis of variance and F test of significance, made on this measurement exactly as was done with per cent recovery, etc. showed a highly significant difference between the standard deviations given in Figure 1. It is found that the most uniform distribution of deposit is obtained by flying crosswind rather than upwind, and at 200 feet rather than 50 feet.

E. The effect of wind and flight altitude on spray drift

Higher altitude flying results in a more uniform distribution because the spray in falling 200 vertical feet drifts farther than in falling 50 feet. The resulting deposit curve from multiple swaths at 200 feet is a composite of a series of wide, flat deposit curves. This curve has as high a mean deposit as the curve for flights at 50 feet with less deviation from the mean.

The data of this experiment were examined for a relation between the drift component of the wind, flight altitude and drift of the spray. "Drift of the spray" was arbitrarily defined as the distance beyond which 50 per cent of the deposit was carried. This information is given for crosswind flights in Table 6 and is plotted in Figure 2. Even though the number of flights is very small it is evident that:

1. With a given altitude drift increases as wind speed decreases.

2. With a given wind speed drift increases with flight altitude.

Table 6. The relation of flight altitude, drift of spray and wind drift

50' altitude			200' altitude		
Flight Number	Drift of spray	Drift comp. of wind	Flight Number	Drift of spray	Drift comp. of wind
	feet	mph		feet	mph
1	210	<1	1	700	-
2	210	1.5	2	325	-
3	260	6.4	3	660	1.3
4	620	9.9	4	675	3.3
5	125	2.0	5	620	2.1
6	200	4.3	6	820	4.0
			7	1440	7.9
			8	800	8.4

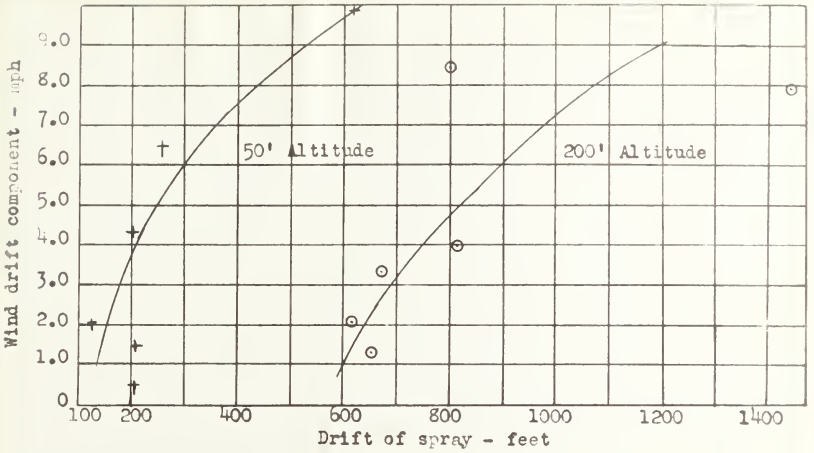

Figure 2. The relation between flight altitude, drift of spray, and the drift component of the wind.

SUMMARY

This experiment was conducted over open ground, with a Stearman plane delivering a spray of 150 microns mass median diameter, and in winds whose drift component varied from 0 to 10 mph. The single swath flights were at 50 feet and 200 feet altitude. Crosswind and upwind flights were included at each altitude. Per cent recovery, maximum deposit and swath widths at various deposit levels were determined from the single swath deposit curves. By assuming (1) swaths every 132 feet and (2) no change in deposit curve from swath to swath, multiple swath curves were obtained from which uniformity of deposit was determined. It should be noted that the number of flights in this experiment is very small; a total sample of 30 flights and no more than 11 flights for any one group.

These measurements gave the following results, applicable to both crosswind and upwind flights:

1. There was no more loss of spray at a 200 foot altitude than at a 50 foot altitude.

2. The spray drifted further at 200 foot altitude, resulting in

3. A more uniform spray distribution at 200 foot altitude in a multiple swath flight.